VIABILITY OF CO-LIQUEFYING COAL AND PLASTIC WASTES

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ABSTRACT

Efforts have been undertaken to assess the technical and economic feasibility of a new process for co-liquefying coal and plastic wastes. This assessment is based on incorporating recent experimental data on plastic/coal liquefaction within a conceptual process framework. A preliminary design was developed to co-liquefy 30,000 kg/hr of plastic waste with an equivalent amount of coal on a weight basis. The plant products include hydrocarbon gases, naphtha, jet fuel and diesel fuel. Material and energy balances along with plant-wide simulation were conducted for the process. Furthermore, the data on plastic-waste availability, disposal, and economics have been compiled. The results from the economic analysis identify profitability criteria for gross profit and return on investment based on variable conversion, yield, and tipping fee for plastic waste processed.

INTRODUCTION

Finding cost-effective energy sources has been a rising concern of our nation for the past twenty years. Coal liquefaction research is at the forefront of potentially feasible options for two reasons. One reason is that coal is the most abundant natural resource readily available in the United States. Furthermore, when coal is liquefied a liquid fraction is produced which can be upgraded to yield transportation fuels (e.g., jet fuel, gasoline, diesel fuel, etc.). At present, the liquefaction of coal alone is not economically feasible. One way of rendering the liquefaction process feasible is to include additional raw materials (e.g. municipal solid waste) that can significantly alter the process economics.

In addition to the energy problem, environmental issues have also been the focus of public attention. The solid-waste problem has escalated to a staggering magnitude. Efficient ways of disposing of/converting solid wastes must be determined. Thus, more focus has been placed on co-processing of coal with waste materials (e.g., tires, plastics, cellulosic material, waste oil, etc.). This alternative is attractive mainly because the waste materials, when co-processed with coal, provide a raw material that increases production capacity and can improve the process economics. This directly offers hope for potential commercialization.

Recent research efforts (Taghiei et al., 1993; Anderson and Tuntawiroon, 1993) have shown that the conversion of coal and plastic waste into liquid fuel is possible on a lab scale. This conversion is achieved by processing coal and waste plastics at a relatively high temperature (400 - 450 ^{o}C) and moderate to high hydrogen pressure (800 - 2000 psi). Conversion as high as 100% is achievable for reactions involving plastic waste alone with yields to the oils fraction ranging between 86 - 92% (Taghiei et al., 1993). However, coal/plastic mixtures attain somewhat lower conversions and yields ranging from 53 - 93% and 26 - 83%, respectively. The oil fraction is the portion of the product that can be refined to yield naphtha, light, middle, and heavy distillates. Therefore, it is important to achieve good conversion and to attain high yields to oils.

The objective of this paper is to provide a technical and economic assessment of co-liquefying coal and plastic waste. First, the availability and current technologies for utilizing plastic waste is reviewed. Then, the problem to be addressed in this work is formally stated. A process flowsheet is conceptualized. Then, the material and energy balances for the process along with a plant-wide simulation using the software ASPEN PLUS will be undertaken. Finally, the economic aspects of the process will be analyzed and some profitability criteria will be assessed.

PLASTIC WASTE AVAILABILITY AND CONVERSION

Each year, our nation produces an estimated 58 billion pounds of plastic resin 90% of which are used in the United States (Hegberg et al, 1992). Lat year, approximately 32 billion pounds of plastics have entered into the municipal solid waste [MSW] stream as post-consumer plastic waste. The MSW generated annually totals 200 million tons and is composed of yard wastes (17.6%), paper (40%), metals (8.5%), glass (7.0%), plastics (8.0%), food wastes (7.4%), and other material (11.6%). Although plastics make-up only 8% of the MSW by weight, of the estimated 400 million cubic meters of annual MSW, plastic wastes are responsible for 20%. This fact creates a major concern for the dwindling legal landfills that already have limited room. Landfilling as an option of disposal is becoming an expensive, undesirable alternative. The average cost for landfilling today is \$20/ton and can be as expensive as \$150/ton depending on location. Landfills are also becoming unacceptable because of social and public-health reasons (e.g. they provide breeding grounds for mosquitoes). Despite the problems associated with landfilling, the low recycling rates for plastics (<1.5%) suggest that plastics end up in landfills or are perhaps illegally dumped.

PROCESS CONCEPTUALIZATION AND SIMULATION

The first step in designing the process for co-liquefying coal and plastic wastes is to develop a conceptual flow sheet. The conceptualized process flow diagram is schemtically illustrated in Figure 1. The waste plastics are sent to a shredder which chips the plastics into processible pieces. Coal is first crushed then distributed to the slurry mixer and to hydrogen generation. The waste plastics and crushed coal are mixed with a recycled solvent to form a slurry. This slurry mixture is fed to a preheater. The preheated slurry is then forwarded to an adiabatically operated reactor which yields vapor, liquid and solid products. The vapor, leaving the reactor at 800 °F and 2200 psi, is first relinquished of hydrogen which is recycled back to the reactor after being mixed with the fresh hydrogen feed. The remainder of the stream is then separated into vapor and liquid products by utilizing a flash column. The gas leaving this flash column is sent to an acid-gas removal system. The remaining gas consists of light petroleum fuel gases. The removed hydrogen sulfide is processed in a Claus unit to yield elemental sulfur. The slurry leaving the reactor is first flashed in the gas oil column. The column yields a vapor product which contains most of the valuable hydrocarbon fractions. The bottom product leaving the column includes heavy hydrocarbons along with the unreacted coal and ash. The vapor stream leaving the gas-oil flash column is hydrotreated and distilled to yield light, middle and heavy distillates. A hydroclone is employed to process the bottoms from the gas oil flash column. The product leaving the top of the hydroclone contains the heavy boiling point fraction (>650 °F). This fraction is recycled to the slurry mixer as a hydrogen-donor solvent. Additional liquid from the fraction is removed using the Wilsonville evolved Residuum Oil Supercritical Extraction-Solid Rejection [ROSE-SR] unit. The recovered liquid is combined with the recycled solvent and this mixture is returned to the slurry mixer. The solid effluent from the ROSE-SR unit, along with some fresh coal, are then used to generate hydrogen needed for processing. A useful fuel gas is also produced in the hydrogen generation process.

Having developed a conceptual flow sheet for the process, one is now in a position to simulate the plant and conduct the necessary calculations for material and energy balances as well as other technical aspects. Material and energy balances for the plant have been conducted. In addition, a plant-wide simulation has also been undertaken using the software ASPEN Plus. Optimization of some units/systems has been carried out to minimize capital and operating costs. In order to yield an environmentally benign plant, the removal and recovery of the sulfur by-product has been achieved via a desulfurization system. Heat integration has also been done for all process streams.

ECONOMIC ANALYSIS

In this section, the economic aspects of this co-processing plant are discussed. Fixed capital investment, total capital investment, total production cost, and annual revenue is evaluated initially. Next, a profitability analysis is accomplished by analyzing the effects of varying conversion, yield and tipping fee on process economics.

Fixed Cost Estimation

Estimation of fixed cost is done by identifying the total purchased equipment cost by relating equipment capacity to cost utilizing available data in literature (e.g., Peters and Timmerhaus, 1991). In particular, the cost of several pieces of equipment was determined by scaling-down based on a recent Bechtel/Amoco study (US DOE-PETC, 1993). This DOE-funded study provides an extensive economic evaluation of direct coal-liquefaction in which Illinois #6 coal is liquefied to yield naphtha, light, middle, an heavy distillates. Design aspects throughout the plant were taken from several pre-existing liquefaction projects (Breckinridge, Wilsonville, HRI, etc.). Based on the capacities of the pieces of equipment needed in this co-liquefaction study, the cost may be calculated using the suggested Bechtel/Amoco scaling exponent of 0.71. For example, at 70% conversion and 90% yield, the total purchased equipment cost is about $77 million. The liquefaction system (reactor, ebullating pumps, etc.), accounting for $42 million (approximately 55% of the total purchased equipment cost. This high cost is due to the very specialized design of the ebullated-bed liquefaction system needed for this type of conversion. From this purchased equipment cost, the fixed and total capital investments were estimated to be $373 million and $439 million, respectively.

Total Production Cost

The total production cost has two components; operational and depreciation costs. The main contributors to operational cost are the cost of shredding plastic waste and the cost of raw material and catalyst needed for liquefaction and hydrogen production. The plant utilizes 30,000 kg/hr of waste plastics that must be shredded before being processed. The cost of shredding is about 5 million/yr based on plant operation of 8760 hours per annum and unit cost for shredding of $0.02/kg. The cost of raw material is an important element in calculation of operational cost. This plant also utilizes and additional 20,000 kg/hr of coal for the production of hydrogen which costs about $10 million/yr (based unit cost for coal of $20.5/ton). The amount of catalyst needed for liquefaction and hydrogen generation can be calculated by scaling down based on capacities and cost available in literature (US DOE-PETC, 1993) and assuming that the catalyst cost-capacity functionality behaves linearly. The estimated cost of catalyst for this facility is about $7 million per annum. Also, waste plastics may have a positive raw material cost if incoming plastics to be processed is paid for, or a negative raw material cost (i.e., generate revenue) if a tipping fee is charged for all incoming plastics to be processed. This issue will be discussed later. The total annual operating cost, excluding depreciation, is approximately 22 million/yr. By using a 10-year straight-line depreciation scheme, one obtains an annual total production cost of $59million/yr for conversion and yield of 70% and 90%, respectively. Similarly, the total production cost can be evaluated at various conversions and yields.

Annual Sales

Annual revenue which is obtained in this facility is partially attributed to the sale of the liquid and gaseous fuels produced in process. At 90% yield and 70% conversion, $60,000 kg/hr of oil and gaseous products is produced. The average value of oil was assumed to be $0.68/gal, which translates into $79 million per annum. Revenue can also gained via tipping fees charged for all plastic waste processed at this facility. Annually, 263 million kilograms of plastic waste are processed in this facility. Processed plastic wastes can potentially generate revenue. For example, this facility can function as a non-conventional waste-management facility at which plastic waste material is disposed. In this case, a tipping fee is charged for all waste materials disposed/processed. The tipping fees will increase the annual revenue generated. In general, plastic wastes can be a source of revenue (via tipping fees) or an expenditure (through vendor charges). For this case study, the tipping fee was varied from free disposal (-$0.06 to 0.02/kg). The $ 0.02/kg corresponds to the plant collecting two cents on each kg of plastic waste as tipping fees. On the other hand, -$0.06/kg corresponds to a post-consumer plastic material which is purchased from a vendor for six cents per kilogram. At a tipping fee of $0.02/kg, as shown in Figure 2, the annual revenue generated from processing waste material is about $5 million. This leads to a total annual revenue of $84 million for the entire plant. At a tipping fee of -$0.06/kg (the least profitable scenario), 70% conversion, and 90% yield, the annual cost of processing plastic waste material is approximately $16 million. The total annual revenue for this scenario is about $63 million.

Profitability

Two important indicators, commonly used in economic assessment, are gross profit and return on investment [ROI]. Gross profit is defined as the difference between the total annual revenue and the total production cost. ROI is determined by dividing this gross profit by the total capital invested. Gross profit and ROI were calculated for several scenarios which include a range of 70 to 90% for yield, 15 to 90% for conversion, and -$0.06 to 0.02/kg for tipping fee. As conversion increases, profitability also increases. For example, at 70% conversion, 90% yield, and a tipping fec of $0.02/kg, the gross profit is $25 million, as shown in Figure 2. By recalling that the total capital investment for degree of conversion and yield is 439 million dollars, the ROI is approximately 5.7%, as shown is Figure 3. The most profitable scenario assessed in this case-study exists at 90% conversion, 90% yield, and a $0.02/kg tipping fee. For this case, the annual gross profit and ROI have been determined to be approximately 30 million and 7.8%, respectively.

CONCLUSIONS

We have conducted a survey of the current status and availability of plastic wastes. Technical assessment of the proposed conceptual plant, process simulation, and economic analysis have be undertaken. Preliminary screening reveals that it is readily feasible to break-even at reasonable conversion, yield, and tipping fee. In this case, a co-liquefaction facility may be viewed as a waste-management facility for the disposal of plastic waste material and generation of fuel. However, if high ROI and annual gross profit are required, higher tipping fees must be charged for processing waste plastic material or further research must be conducted to identify ways of attaining higher conversion and yield.

BIBLIOGRAPHY

Anderson, L. L. and W. Tuntawiroon, “Co-Liquefaction Coal and Polymers to Liquid Fuels”, Preprints of ACS Meeting, Chicago, pp. 816-822, August 1993.

Taghiei , M. M., F. E. Huggins and G. P. Huffman, “Co-Liquefaction of Waste Plastics with Coal”, Preprints of ACS Meeting, Chicago, pp. 810-815, August 1993.

Hegberg, B., G. Brenniman, W. Hallenbek, 1992, "Mixed Plastics Recycling Technology", Noyes Data Corporation, Park Ridge, NJ.

Peters, M. and K. Timmerhaus, 1991, "Plant Design and Economics for Chemical Engineers", 4th ed., Chemical Engineering Series.

U.S. DOE Pittsburgh Energy Technology Center [PETC], 1993, "Direct Liquefaction Baseline Design and System Analysis", Final Report on Baseline and Improved Baseline, vol. IIa, March.

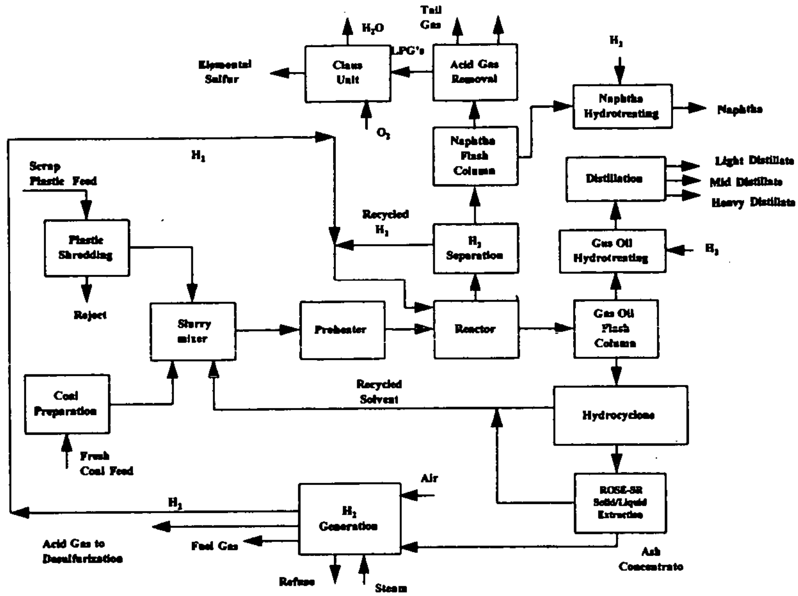

Figure 1: Conceptual Process Flow Diagram for the Co-Liquefaction Plant

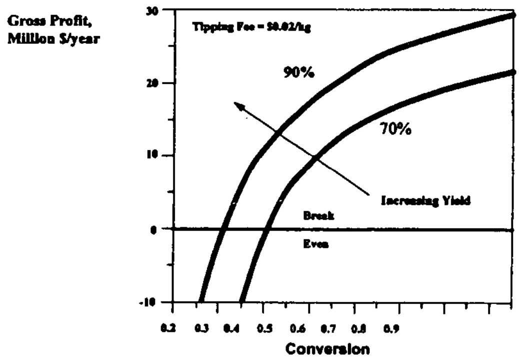

Figure 2: Gross Profit

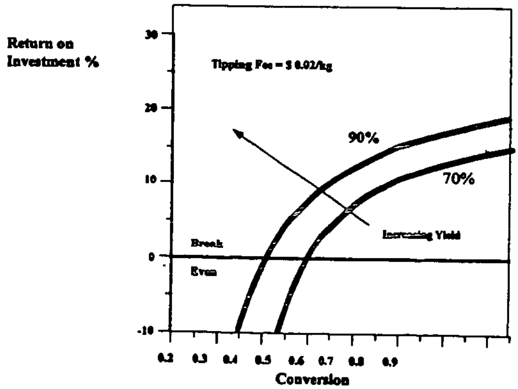

Figure 3: Return on Investment